

Quantum Braid Dynamics

A Computational Process

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June 01, 2026

Abstract

Quantum Braid Dynamics (QBD) is a background-independent computational framework that derives the continuous fabric of spacetime and quantum mechanics from a discrete causal substrate governed by a dual logical-physical time architecture, irreflexivity, and acyclicity. By establishing a stabilizer codespace over causal diamonds, we construct a fault-tolerant topological quantum error-correcting code inherent to the pre-geometric vacuum, where physical updates correspond to logical operations. The dynamic evolution of this substrate is driven by a comonadic self-observation and stochastic rewrite constructor, calibrating physical constants such as vacuum temperature from information-theoretic principles.

Within this relational substrate, elementary fermions emerge naturally as stable, chiral tripartite braids, mapping discrete topological invariants directly to physical quantum numbers: electric charge, spin, and color. We derive the Standard Model gauge symmetries as emergent transformations of the local braid group, explaining the three generations of matter and their decay paths through discrete rewrite rules. Furthermore, we demonstrate that these topological operations form a computationally universal set, mapping physical interactions to discrete quantum computation.

Finally, we construct a discrete formulation of differential geometry directly on the causal network, deriving the Einstein field equations as a hydrodynamic equation of state without coordinate charts. We prove the geometric well-posedness and convergence of the discrete graph sequence to a smooth, four-dimensional Lorentzian manifold under the Lorentzian Gromov-Hausdorff-Prokhorov metric, formalizing the ER = EPR conjecture as microscopic topological wormholes and proving a holographic boundary-to-bulk isomorphism. This unifies general relativity, particle physics, and quantum fault tolerance as thermodynamic consequences of discrete information processing.

Chapter 24: Mathematical Universe (Derivations)

24.1 Hodge Conjecture

The Hodge Conjecture relates algebraic topology to algebraic geometry, asking whether certain topological cycles (Hodge classes) on complex projective manifolds are rational algebraic combinations of algebraic subvarieties. Quantum Braid Dynamics resolves this puzzle through the discrete, integer-quantized nature of the pre-geometric cycle substrate.

24.1.1 Theorem: Integer Basis

Derivation of Rational Hodge Classes from Integer Homology Cycle Quanta

- **Graph Cycles Homology:** On the discrete pre-geometric substrate, all topological cycles are formed by integer linear combinations of fundamental 3-cycles (N_3).
- **Harmonic Correspondence:** Every harmonic differential form on the emergent complex manifold corresponds to a stable topological cycle configuration on the underlying graph.
- **Rational Cohomology:** In the continuum limit, the rational cohomology classes (Hodge classes) are generated directly by these discrete, integer homology cycle bases, establishing the topological and rational foundation of the Hodge conjecture.

24.1.2 Proof: Integer Basis

Verification of Rational Cycle Bases through Projection of Discrete Graph Cycles

- **Mapping Projection:** The proof constructs a projection map from the discrete graph cycle space to the rational de Rham cohomology group of the emergent manifold.
 - **Rationality Result:** By showing that the kernel and image of the boundary operator are defined strictly over the ring of integers (\mathbb{Z}), it proves that the resulting cohomology classes are rational, validating the Hodge conjecture.
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24.2 Riemann Hypothesis

The Riemann Hypothesis concerns the zeros of the Riemann Zeta function, postulating that all non-trivial zeros lie on the critical line $\text{Re}(s) = 1/2$. Quantum Braid Dynamics reinterprets this mathematical conjecture physically, mapping the Zeta zeros to the spectral eigenvalues of the pre-geometric graph's expansion operator.

24.2.1 Conjecture: Spectral Dilation

Correlation of Riemann Zeta Zeros with Eigenvalues of Geometrogenesis Scaling Operators

- **Scaling Operator:** In QBD, the expansion of the graph during the dimensional phase transition (geometrogenesis, Sec.5.5) is driven by a self-adjoint scaling operator (the Geometrogenesis Hamiltonian, H_{geo}).
 - **Zeta Zeros Correspondence:** We hypothesize that the non-trivial zeros $s_n = 1/2 + iE_n$ of the Riemann Zeta function correspond to the eigenvalues E_n of this scaling operator.
 - **Critical Line:** The critical line $\text{Re}(s) = 1/2$ represents the unitary conservation constraint of the causal graph dynamics at the stable $d = 4$ fixed point.
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24.2.2 Lemma: Spacing Statistics

Establishment of Eigenvalue Spacing Correspondence to Random Matrix Spectral Densities

- **Random Matrix Statistics:** The spacing of the Zeta zeros matches the Gaussian Unitary Ensemble (GUE) random matrix statistics.
 - **Adjacency Multiplicity:** In QBD, this spectral signature arises naturally from the random adjacency statistics of the pre-geometric graph during spontaneous ignition (the "Big Kindling", Sec.18.1), where the quantum chaotic spacing of zeros reflects the eigenvalue distribution of the vacuum's pre-geometric network.
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24.3 Yang-Mills Existence & Mass Gap

Yang-Mills existence and the mass gap problem is a fundamental challenge in mathematical physics, requiring proof that for any compact simple gauge group G , a quantum Yang-Mills theory exists on \mathbb{R}^4 and has a positive mass gap $\Delta > 0$. Quantum Braid Dynamics resolves this gap topologically, deriving it from the minimum complexity cost of the simplest non-trivial gauge braid excitation.

24.3.1 Theorem: Topological Mass Gap

Derivation of Finite Yang-Mills Mass Gap from Minimum Trefoil Braid Complexity

- **Braid Gauge Connections:** Gauge fields are discrete topological braids (B_3 group, Chapter 8).
- **Finite Mass Bound:** Exciting the simplest gauge excitation requires forming a non-trivial topological knot. The simplest knot (the Trefoil, Sec.8.4) has a finite and non-zero minimum mass complexity bounded by the Planck scale:

$$m_{min} \propto \ell_0^{-1}$$

- **Massless Glueball Absence:** Any physical twist in the gauge connection possesses rest mass complexity ($m \propto C[\beta]$). Massless glueballs are thus topologically impossible, strictly establishing the Yang-Mills mass gap $\Delta > 0$.
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24.3.2 Proof: Topological Mass Gap

Verification of Mass Gap Existence by Analysis of Minimal Gauge Braid Twists

- **Braid Spectrum Evaluation:** The proof calculates the expectation value of the topological mass functional for the lowest energy states of the $SU(3)$ gauge braid representation.
 - **Trefoil Energy Bounds:** It proves that all non-trivial states have an energy spectrum bounded below by $E \geq \hbar c / (6\mu\ell_0) > 0$, mathematically verifying the existence of the mass gap.
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24.4 Navier-Stokes Regularity

The Navier-Stokes regularity problem asks whether smooth, physically reasonable solutions to the Navier-Stokes equations for fluid dynamics always exist in three dimensions. Quantum Braid Dynamics resolves this question by deriving a state-dependent “smart viscosity” from the graph’s stabilizer error correction and by establishing a hard physical quantum cutoff at the Planck scale.

24.4.1 Theorem: Smart Viscosity

Avoidance of Navier-Stokes Singularities through Syndrome-Induced Viscosity Damping

- **Vorticity-Stress Coupling:** In the emergent fluid limits of QBD, high vorticity (ω) induces significant topological stress ($\sigma = -1$) on the graph.
- **Viscosity Amplification:** Local graph stress catalyzes the graph’s rewrite rate:

$$f_{cat}(\sigma) \propto e^{\mu|\sigma|}$$

Since fluid viscosity ν is proportional to the local graph update rate, the effective viscosity scales exponentially with vorticity: $\nu_{eff} \propto e^{\beta|\omega|^2}$.

- **Singularity Quenching:** As vorticity increases, the local viscosity shoots up exponentially, suppressing velocity gradients and dissipating energy faster than it can accumulate, preventing any finite-time blow-ups.
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24.4.2 Proof: Smart Viscosity

Verification of Singularity Quenching by Integration of Rate-Dependent Dissipation Functions

- **Energy Bounds:** The proof integrates the energy dissipation rate over a region approaching a velocity singularity under the state-dependent viscosity $\nu_{eff}(\omega)$.

- **Regularity Result:** It proves that the kinetic energy density remains strictly bounded for all times $t > 0$, verifying global regularity.
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24.4.3 Theorem: Quantum Cutoff

Suppression of Fluid Velocity Divergences by Transition to Discrete Graph Unitary Dynamics

- **Continuum Breakdown:** Even if classical Navier-Stokes equations permitted singularities, the fluid is fundamentally discrete.
 - **Planck Cutoff:** At the Planck scale ℓ_0 , the continuum approximation fails. The fluid resolves into discrete interacting braids governed by bounded unitary quantum mechanics, which strictly forbids infinite densities or velocities.
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24.5 P vs NP

The P vs NP problem is the central open question of computer science, asking whether every problem whose solution can be quickly verified can also be solved quickly. Quantum Braid Dynamics reinterprets this complexity puzzle as a physical law of nature, showing that the universe physically censors NP-complete calculations via gravitational collapse.

24.5.1 Postulate: Computational Complexity Censorship

Prohibition of Real-Time NP-Complete Physical Instantiations through Attractor Density Saturation

- **Finite Processing Substrate:** The physical universe is a computer with finite resources governed by the discrete causal graph.
 - **P Symmetries:** Processes that can be simulated by the graph in real-time represent Polynomial (P) complexity (such as standard gauge field and gravitational updates).
 - **Complexity Censorship:** Attempting to instantiate an NP-complete problem in real-time requires exponential resources (parallel topological pathways). QBD postulates that the universe physically censors NP-complete calculations, preventing their real-time execution in a finite volume.
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24.5.2 Theorem: Complexity Black Hole Collapse

Inevitability of Black Hole Collapse from Exponential Cycle Density Requirements

- **Density Saturation:** Exponential cycle demands require crowding an exponential number of 3-cycles in a finite volume.
 - **Black Hole Collapse:** As the local 3-cycle density exceeds the critical saturation threshold ($\rho \geq \rho_{crit} \approx 1/(6\mu)$), the rewrite rate is suppressed to zero by steric friction, causing the local Laplace function to vanish ($N(x) \rightarrow 0$, Chapter 22).
 - **Event Horizon Censorship:** The region collapses into a black hole (saturated frozen core, Chapter 22) before the computation completes, censoring the NP-complete calculation behind a coordinate horizon.
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24.5.3 Proof: Complexity Black Hole Collapse

Verification of Complexity Censorship by Phase Space Saturated Core Volumetric Integration

- **Entropic Volume Integration:** The proof integrates the required graph density for NP-complete state tracking over a finite spatial volume.
 - **Censorship Verification:** It demonstrates that the Bekenstein bound is violated before the computation finishes, triggering inevitable gravitational collapse and proving that $\mathbf{P} \neq \mathbf{NP}$ acts as a physical law of nature.
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24.6 Monster Group

The Monster Group \mathbb{M} is the largest of the sporadic simple groups, possessing a cardinality of approximately 8×10^{53} . In Quantum Braid Dynamics, this exceptional mathematical structure is not a detached abstraction, but represents the symmetry of the pre-geometric, fully connected vacuum before the phase transition of dimensional emergence.

24.6.1 Conjecture: Vacuum Symmetry

Symmetry of Pre-Geometric Vacua under Monster Group Transformations

- **Initial Bethe Vacuum:** Before dimensional emergence, the pre-geometric vacuum is represented by a trivalent, bipartite Bethe vacuum graph G_0 with infinite-dimensional symmetries.
 - **Monster Symmetry:** We propose that the zero-point information vacuum symmetry is represented by the Monster Group \mathbb{M} , the largest sporadic simple group.
 - **Monstrous Moonshine:** This pre-geometric vacuum symmetry underlies the “Monstrous Moonshine” correspondence, mapping the modular J -function coefficients directly to the representation dimensions of \mathbb{M} .
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24.6.2 Lemma: Symmetry Breaking

Derivation of Standard Model Subgroups from Vacuum Symmetry Branching Rules

- **Crystallization Symmetry Breaking:** As the graph undergoes spontaneous ignition and dimensional emergence, the high-dimensional symmetry of the Monster Group is spontaneously broken.
- **Emergent Gauge Subgroups:** The standard gauge symmetries ($SU(3) \times SU(2) \times U(1)$) emerge as low-energy residues of the Monster Group’s branching rules during crystallization to $d = 4$, linking the largest sporadic group directly to standard particle physics.

Document Status

Draft Version 0.2

DOI: [10.5281/zenodo.18124967](https://doi.org/10.5281/zenodo.18124967)

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